

Macro- and Micro-habitat Relationships of Adult and Sub-Adult Rockfish, Lingcod, and Kelp Greenling in Puget Sound

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Introduction

Marine refuges are becoming increasingly important as fishery management and habitat conservation tools throughout the world. In Washington State, the Washington Department of Fish and Wildlife (Fish and Wildlife) has begun using refuges in an attempt to conserve and rebuild stocks of several depressed rockfish species in Puget Sound. Although scientific criteria have seldom been used as the basis for siting most of the world's existing marine refuges (Roberts 2000), numerous refuges have shown significant increases in species density, biomass, and bio-diversity (see reviews by Roberts and Polunin 1991; Dugan and Davis 1993; Rowley 1994). Roberts (2000) suggests that high-quality habitats may attain greater biomass and bio-diversity than low-quality habitats. Thus by incorporating the habitat requirements of the target species into the design and siting process, greater benefits may be derived over refuges placed with little or no regard for habitat quality.

Copper rockfish *Sebastes caurinus* and quillback rockfish *S. maliger* are sedentary, structure-oriented benthic species commonly found in the shallow waters of the northeast Pacific Ocean from central California to the Gulf of Alaska (Hart 1973). The species are morphologically similar, differing mainly in coloration, and occur sympatrically in many areas of the inland marine waters of Washington State. (Matthews 1990a, Fish and Wildlife, unpub. data). Populations of copper and quillback rockfish have undergone significant declines in both mean size and abundance over the past several decades, due mainly to pressure from increased recreational fishing activities (Puget Sound Water Quality Action Team 2000).

Lingcod *Ophiodon elongatus* and kelp greenling *Hexagrammos decagrammus* are members of the Family Hexagrammidae, and are commonly found in the same habitats utilized by copper and quillback rockfish. Lingcod are highly valued by sports fishermen, and populations in some areas of Puget have shown long-term or historic declines (Puget Sound Water Quality Action Team 2000). As a consequence of their overlapping distribution with rockfish and lingcod, kelp greenling have also been subjected to increased levels of recreational fishing effort, however, there is no evidence to suggest that their populations have undergone any substantial decline. Copper rockfish, quillback rockfish and lingcod typically exhibit small home range movements and have demonstrated the ability to relocate their home ranges after displacements of up to several kilometers (Matthews 1990b,c), making them excellent candidates for protection through the development of marine refuges.

Bottom topography, substrate, and other physical features have been shown to influence the distribution and abundance of rockfish, lingcod, and kelp greenling on a large (i.e., meso-habitat) scale (Richards 1986; Richards 1987; Stein and others 1992; Murie and others. 1994). However, within a given meso-habitat (e.g., rock reef), physical features (e.g., vertical relief, slope, crevice size, biological cover) often show considerable fine-scale spatial variability, further affecting the distribution of fishes within the larger area. Depth has also been reported as an important variable influencing the distribution of rockfish, with similar species often occupying different bathymetric ranges (Chen 1971).

Since 1992, Fish and Wildlife staff have conducted underwater video surveys of rocky reef fishes in Puget Sound. During these surveys, we have observed that rockfish, lingcod, and kelp greenling appear to show some obvious and consistent patterns of habitat use, apparently in response to fine-scale physical features in their environment. Based on habitat information collected during Fish and Wildlife video surveys, we examine the relationships of these four common rocky reef species in Puget Sound to several macro- and micro-habitat variables, and discuss the implications of our results as they pertain to the design and placement of MPAs in Puget Sound.

Methods

Fish and Wildlife staff collected data during underwater video surveys of shallow (0-37 m mllw) rocky reef fishes and their habitats in Puget Sound. Surveys have been conducted annually and on a rotating basis since 1993 throughout the seven Fish and Wildlife Groundfish Management Regions encompassing the inland marine waters of the state of Washington eastward from Cape Flattery (hereafter referred to as Puget Sound). The camera system for all surveys consisted of a Deep Sea Power and Light black-and-white CCD underwater television camera and 250 watt floodlamp attached to a Remote Ocean System PT-25 pan and tilt motor. The camera system was suspended from the apex of the camera platform, a 1.5 m tall pyramid constructed of 3.5 cm diameter steel reinforcing rods (rebar). Lead weights were added to the base of the platform to improve stability in high currents and on steep slopes. All camera system functions were surface-controlled from the Fish and Wildlife support vessel R/V *Molluscan* via a 2.5 cm diameter multi-strand underwater electrical cable connected to a Remote Ocean System controller. A 2 cm diameter braided kevlar line attached to the camera platform was used to raise and lower the platform from the support vessel. The dry weight of the platform, weights, and camera system was approximately 75 kg.

At each video station, the camera was lowered to the bottom and allowed to stabilize in an upright position. After achieving a stabilized position, the camera was panned and tilted throughout the 360-degree field of view to record all fishes occurring up to 2 m above the bottom. A minimum of two 360-degree pans was required for a deployment to be considered valid; however, unless current or weather conditions were severe, a minimum of three pans was accomplished at each video station.

Survey videotapes were reviewed in the laboratory following each video survey. All fishes and economically important invertebrates were identified and enumerated for each camera sweep, and only fishes inhabiting the bottom 2 m of the water column were counted. Only the counts from the last valid camera pan were used for calculating the individual taxa densities at each station. The visible range of the camera was estimated for each deployment based on observer experience and visibility experiments conducted before and after each survey.

In all surveys, four habitat variables were recorded for each camera deployment; substrate type, vertical relief, habitat complexity, and biological cover, however, only the first three variables are considered in this study (Table 1). We have adopted the terminology of Greene and others (1999) as the basis of our habitat categories, where *macro-habitats* range in size from 1 to 10 meters and include seafloor materials (e.g., substrate) and features (e.g., boulders, reefs, crevices, cracks, bedrock outcrops) and *micro-habitats* include seafloor materials and features that range in size from centimeters to a meter (e.g., sand, pebbles, gravel, small cracks and crevices). The maximum functional visible range of the camera system is approximately 8 to 10 meters in diameter (depending upon local water clarity), thus the definitions of macro- and micro-habitat used above are appropriate for the sampling protocol. At each video station, the seafloor was characterized by the two dominant substrates present at the site. Video stations containing any amount of rock substrate were always scored as rock stations. Non-rock stations where the dominant substrate was composed of gravel, cobble, or shell hash (or any mixture thereof) were scored as coarse grain, while stations where the dominant substrate was sand or mud were scored as fine grain. Vertical relief was scored as the maximum relief present at each station (e.g. if the camera landed on a flat, mud bottom at the base of a slope $>45^{\circ}$, the station was scored as wall). Habitat complexity was scored based on the overall irregularity (rugosity) of the habitat and the number of crevices and interstitial spaces large enough to provide refuge for sub-adult or larger rockfish.

For each video station, density estimates for each taxon were calculated by dividing the number of individuals C observed during the last valid camera pan by the area (a) viewed during the deployment. The viewing area (a) was determined by using the estimated visibility (V) as the radius in the area of a circle. Thus, for each taxon, density (f) was estimated as:

$$f = \frac{C}{a} = \frac{C}{(\pi V^2)}$$

Table 1. Habitat variables used in Fish and Wildlife bottomfish video surveys.

Variable	Score	Description
Substrate	Rock	hardpan (clay, sandstone), bedrock, boulder
	Coarse grain	gravel, cobble, shell hash
	Fine grain	sand, mud
Relief	None	flat or rolling substrate with vertical relief up to 0.5 m
	Low	vertical relief from 0.5 m to 2 m
	High	vertical relief >2 m, slope <45 degrees
	Wall	vertical relief >2 m, slope ≥ 45 degrees
Complexity	Simple	smooth surfaces, no crevices
	Low	some irregularity, few crevices (<25% of area)
	Medium	moderate irregularity, ~25-50% of habitat with crevices
	High	highly irregular, many crevices (>50% of area with crevices)

Data Analysis

Kruskal-Wallis analysis was used to test for differences in fish density between depth zones and substrate type for each species. Two-way ANOVA's were used to test for differences in fish density between relief and complexity variables. To correct for problems of heteroscedasticity, the fish density data were square-root transformed, where $X' = \sqrt{X} + \sqrt{(X+1)}$.

Results

From 1993 to 1998 Fish and Wildlife staff completed 2,558 video deployments during annual video surveys of Puget Sound (Figure 1). Coarse grain and fine grain substrates comprised the majority of the habitats sampled, with rocky substrates present at only 43% of the video stations sampled (Figure 2). Copper rockfish, quillback rockfish, lingcod, and kelp greenling were observed in all survey years, and the data were pooled across years for each species for all analyses.

To test for the effect of bottom depth on species abundance, data were grouped into three depth strata: 0-13 m; 13-27 m; and >27 m. Quillback rockfish was the only species to show a significant response to bottom depth (Figure 3); over 70% of quillback rockfish observations were made at depths greater than 13 m, with over 40% of all observations occurring at depths greater than 27 m.

Rock substrates in Puget Sound fell into two main categories: low relief/low complexity (frequency of occurrence = 43%) and low relief/moderate complexity (frequency of occurrence = 13%) (Table 2). High relief substrates were uncommon, accounting for <12% of the rocky habitat sampled. Wall habitats comprised 21% of the rock stations surveyed, covering all levels of complexity.

The majority of rock habitats in the video surveys were devoid of fish. Copper rockfish and kelp greenling were the most common species in the video surveys, but were only observed at 22% and 18% of rock substrate stations, respectively. Quillback rockfish were seen at 11% of rock substrate stations while lingcod were present at only 7% of video stations containing rock substrates.

Table 2. Frequency matrix of observed habitat and complexity variables (counts in parentheses).

<u>Complexity</u>	<u>Relief</u>			
	None	Low	High	Wall
Simple	2.96 (33)	4.57 (51)	0 (0)	0.27 (3)
Low	1.79 (20)	42.29 (472)	3.05 (34)	6.36 (71)
Moderate	0 (0)	13.35 (149)	5.73 (64)	8.51 (95)
High	0 (0)	2.78 (31)	2.51 (28)	5.82 (65)

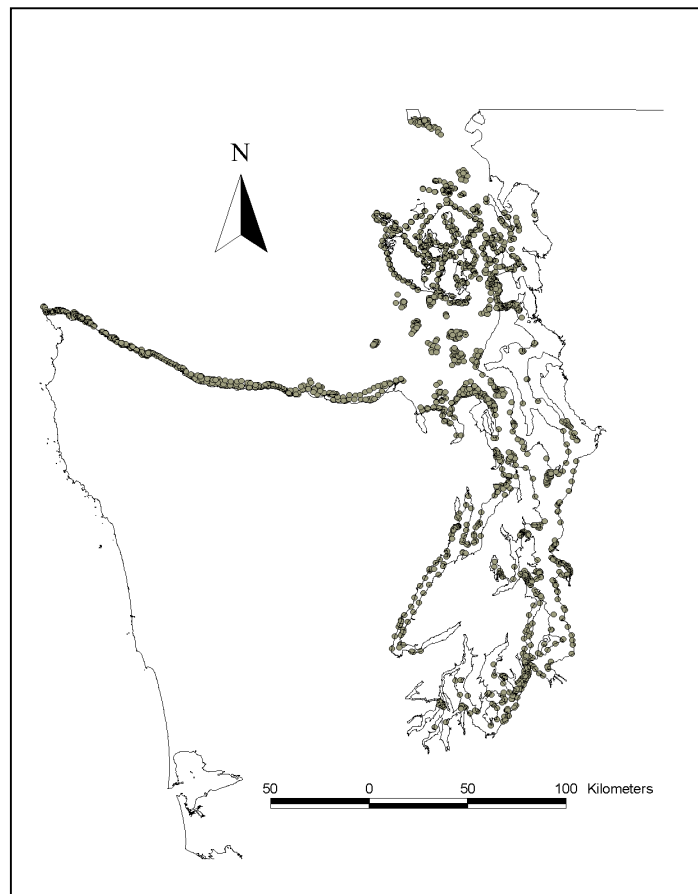


Figure 1. Video deployment locations (filled circles) from Fish and Wildlife bottomfish surveys of Puget Sound (n=2,558)

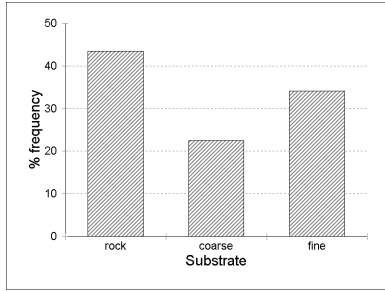


Figure 2. Distribution of substrates observed during Fish and Wildlife video surveys.

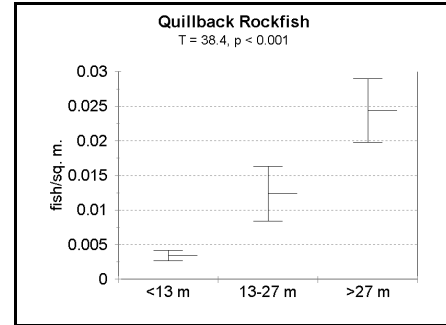


Figure 3. Mean density (+/- 1 s.e.) and Kruskal-Wallis results for quillback rockfish by depth zone.

More than 91% of copper rockfish and 95% of quillback rockfish observations were made at video stations where rock substrates were present (Figure 4). Similarly, over 85% of all lingcod and kelp greenling observations were associated with rock substrates. The mean densities of all species were significantly higher on rock substrates (Figure 5), however, densities did not differ significantly between coarse grain and fine grain substrates. Based on these results, only data from rock substrate stations were used for the remaining analyses.

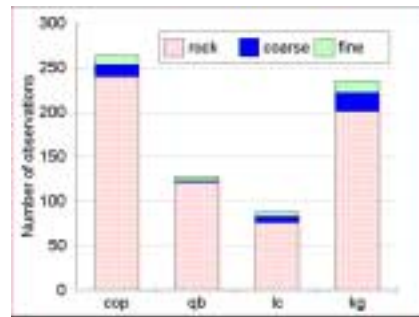


Figure 4. Number of fish observations by substrate type:

cop = copper rockfish
qb = quillback rockfish
lc = lingcod
kg = kelp greenling.

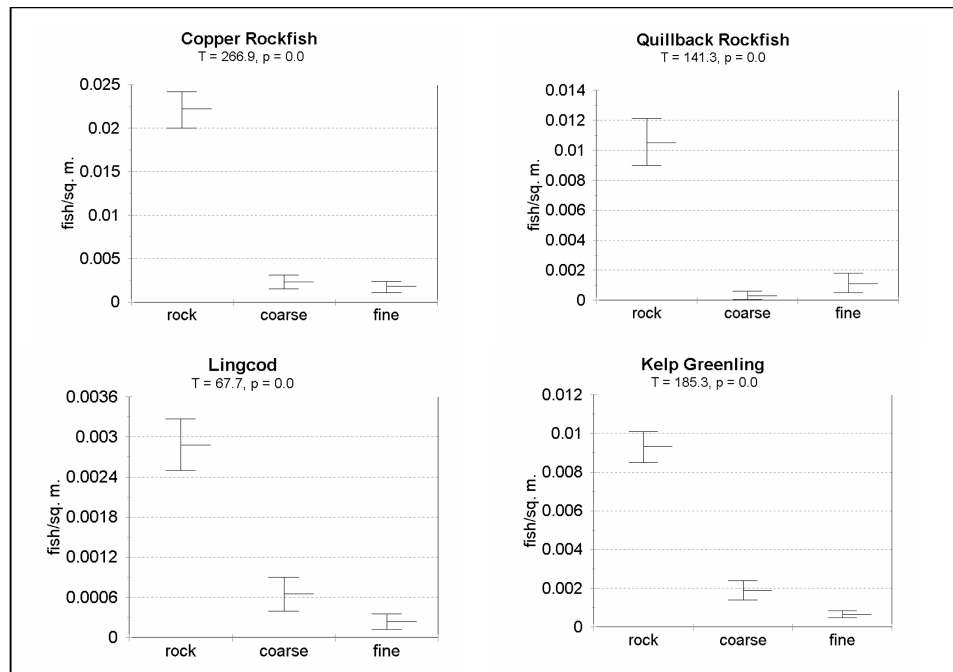


Figure 5. Mean densities (\pm 1 s.e.) and Kruskal-Wallis results for four bottomfish species by substrate type.

The response to vertical relief and habitat complexity varied among the four species (Figure 6). Copper rockfish exhibited significant responses to both relief and complexity, with the highest densities seen on walls and in high complexity habitats. Quillback rockfish did not show a significant response to relief, but demonstrated a strong response to habitat complexity. Lingcod showed weakly significant responses to relief and complexity, while kelp greenling showed no significant response to either habitat variable.

To provide a better understanding of the relationship between the relief and complexity variables, seven generalized rock reef habitats typically encountered during Fish and Wildlife video surveys were constructed from the relief/complexity matrix (Table 3). The fish density data were then analyzed using a Kruskal-Wallis analysis as done for the depth and substrate variables. As expected from the relief-complexity ANOVA results, the patterns of habitat use were not consistent between species (Figure 7). Copper and quillback rockfish showed little use of scoured bedrock or low-relief rock ridges. Copper rockfish exhibited the strongest affinity for complex walls, followed by low-relief and high-relief boulder fields. Densities of quillback rockfish and lingcod were highly variable due to small sample sizes in several categories. Quillback rockfish densities were highest on low relief boulder fields, followed closely by high complexity walls. Lingcod densities were highest on high complexity walls, but not significantly different from simple walls, high relief ridges, or low relief boulder fields. In contrast to the other species, densities of kelp greenling were highest on low complexity walls, but the differences were non-significant compared to all reef types except scoured bedrock and low relief ridges.

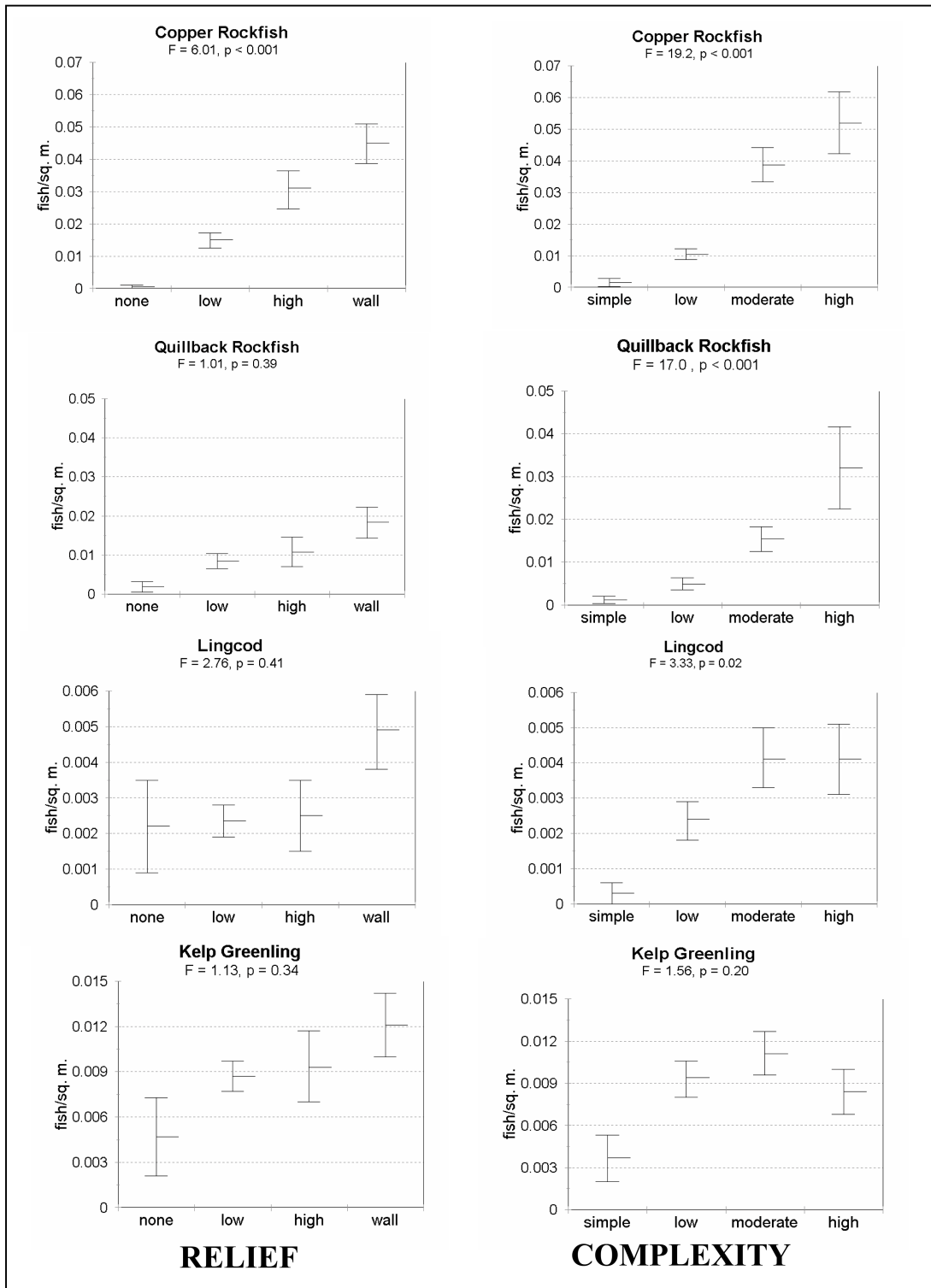


Figure 6. Mean densities (± 1 s.e.) of four bottom fish species, by vertical relief (left column) and habitat complexity (right column). F and p-values from 2-way ANOVA of square-root transformed values.

Table 3. Generalized reef types commonly encountered during Fish and Wildlife video surveys.

Reef Type	Relief level	Complexity level
Scoured bedrock (SCBR)	None	Simple to Low
Low relief rock ridge (LRRR)	Low	Simple to Low
High relief rock ridge (HRRR)	High	Simple to Low
Simple wall (SMWL)	Wall	Simple to Low
Low relief boulder field (LRBF)	Low	Moderate to High
High relief boulder field (HRBF)	High	Moderate to High
Complex wall (CMWL)	Wall	Moderate to High

Discussion

Previous studies of the habitat relationships of copper and quillback rockfish have described the general affinities of these species to large-scale (>10 m) habitat features (i.e., meso-habitats) (e.g., Richards 1986, Richards 1987, Murie and others 1994), but did not consider the fine scale (<10 m) differences in species abundance (patchiness) that often occur within them. Using data from video surveys of rocky reef fishes and their habitats in Puget Sound, we describe the habitat relationships of rockfish, lingcod, and kelp greenling as they occur on a finer (i.e., macro- and micro-) scale.

Substrate composition was clearly an important factor influencing the density of the two rockfish and two Hexagrammid species examined in this study. As their name implies, copper and quillback rockfish were highly associated with rock substrates, with virtually no occurrence of these species on softer substrates. Similarly, densities of lingcod and kelp greenling were significantly higher on rock substrates whereas cobble, gravel, sand, and mud bottoms were seldom utilized. Our results are consistent with submersible observations made by Richards (1986) and Murie and others (1994), who reported copper and quillback rockfish abundance to be greatest in complex (i.e., rocky) habitats. SCUBA studies by Matthews (1990a) also found the highest densities of adult and sub-adult copper and quillback rockfish in natural rock and artificial habitats. Stein and others (1992) examined fish-habitat relationships at depths greater than those we sampled, and found adult lingcod and kelp greenling occurring mainly in rocky habitats, with little utilization of mud bottoms.

Copper rockfish was the only species to show a significant response to vertical relief, however, the somewhat biased nature of the video sampling protocol may have confounded the results of this analysis. Specifically, when sampling steep walls, the camera platform was lowered until it reached a stable position, usually coming to rest on ledge or at the base of the wall. In many cases, these areas were dominated by boulder fields, thus the higher densities of all species seen in wall habitats may actually have been a response to habitat complexity rather than to the level of relief. Disregarding wall habitats, our results are consistent with those of Matthews (1990a), who reported densities of copper rockfish to be highest on high

relief rocky reefs. Further, she observed low densities of copper and quillback rockfish using low relief reefs during summer, and concluded that occupancy of these reefs was mainly a response to the bull kelp *Nereocystis leutkeana*, which grew on the reefs during summer then died back in winter, apparently affording these species a short-term refuge and foraging area.

The strong responses of copper and quillback rockfish to increasing habitat complexity are consistent with the observations of Richards (1987), who reported higher densities of both species to be associated with higher substrate scores (i.e., complexity). Among the natural habitats she studied, Matthews (1990a) observed the highest and most stable densities of adult and sub-adult copper and quillback rockfish on high-relief reefs, which were the most complex habitats in her study. The strong affinity of copper rockfish to higher complexity habitats has also been observed during SCUBA surveys of Puget Sound reefs conducted by the authors (Fish and Wildlife, unpublished data). Because up to 30% of copper and quillback rockfish within the cameras viewing range may be hidden in crevices or otherwise obstructed from view (Fish and Wildlife, unpublished data), we may have substantially underestimated densities of these species, especially in the most complex habitats, thus the importance of habitat complexity may be greater than our results suggest.

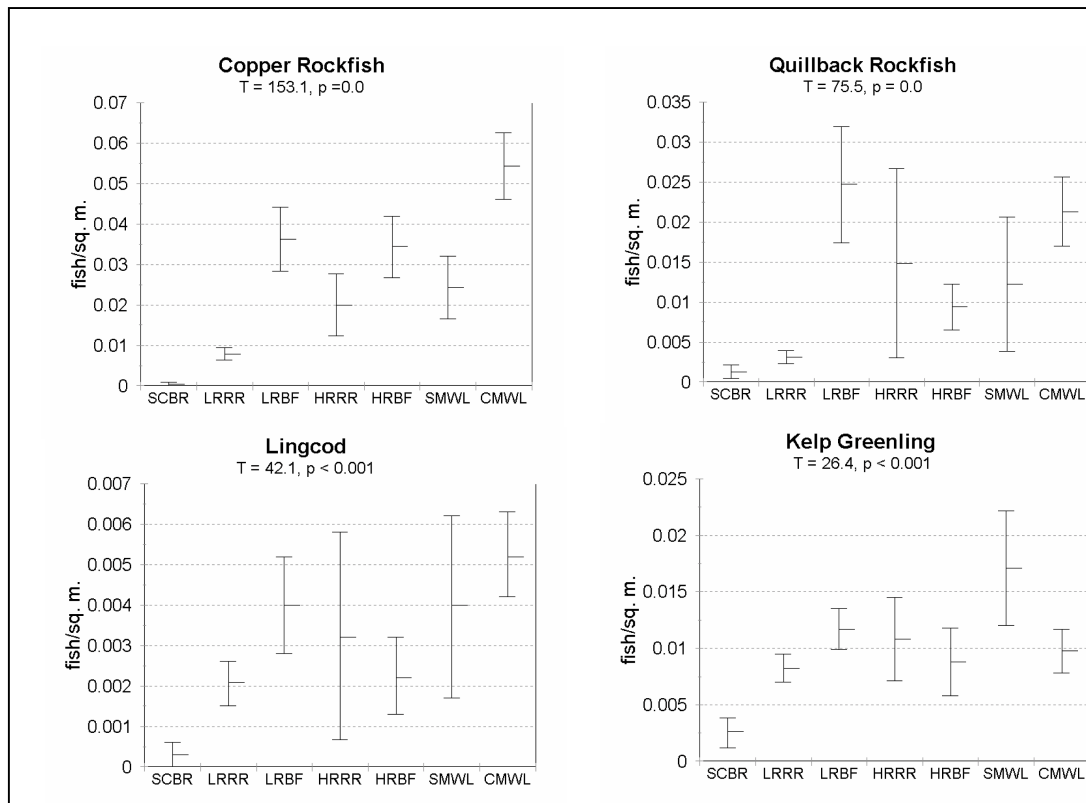


Figure 7. Mean densities (± 1 s.e.) and Kruskal-Wallis results for four bottomfish species by generalized habitat type (see Table 3 for definition of habitat abbreviation.)

Densities of quillback rockfish increased significantly with depth, reinforcing Moulton's (1977) observations that this species occupies a deeper bathymetric range than copper rockfish. Although copper rockfish abundance did not vary over the range of depths we sampled, the preference of quillback rockfish for deeper waters provides some evidence that the two species may segregate bathymetrically. On rocky reefs off the coast of California, *Sebastes carnatus* and *S. chrysomelas* are the morphological and ecological analogs of copper and quillback rockfish. Larson (1979) reported that these species exhibit bathymetric segregation where they co-exist, and hypothesized that a genetic adaptation to prey density was the primary mechanism controlling this process.

The strong preference of copper rockfish for complex walls and boulder fields suggests that habitat complexity may be more important than relief for predicting species abundance. Although Richards (1987) did find a differential response to relief by small and large copper rockfish, no obvious trends were apparent. Also, because her definition of relief included a measure of habitat complexity, the relationship between the two factors is confounded. Unlike their congener, quillback rockfish showed a stronger preference for low relief boulder fields. The species apparent preference for deeper water may offer one explanation for this difference, with the hypothesis that high relief and wall habitats are more limited in deeper waters, resulting in more extensive use of low relief habitats.

Lingcod tended to prefer walls and higher complexity habitats, but the relationships were not significant, likely due to small sample sizes. Kelp greenling showed even less habitat specificity, with similar densities seen across nearly all of our generalized habitats. Because lingcod and kelp greenling were often seen swimming through the video station, we may have captured some individuals crossing unsuitable or non-preferred habitats, in which case, the value of some habitats may be overemphasized by our study. The benthic nature of these species may also have affected our results. For example, the detectability of copper and quillback rockfish was enhanced by their highly contrasting body markings and propensity to hover up to 2 m above the bottom. In contrast, lingcod and kelp greenling possess more cryptic, monochromatic morphologies and were almost always observed in direct contact with the bottom, making them difficult to distinguish in the black-and-white video image. Hence, in habitats where the viewing range was compromised by obstructions (e.g., boulders, ridges), we may have substantially underestimated the abundance of lingcod and kelp greenling, thereby obscuring any response to habitat complexity. Conversely, kelp greenling tended to be more curious than rockfish or lingcod, and may have been positively attracted to the platform. Thus, in areas with less obstructed viewing ranges (i.e., non-complex habitats) where the platform could be more easily detected, we may have overestimated kelp greenling abundance, potentially masking the importance of high relief habitats.

Many of the rocky reefs sampled during Fish and Wildlife video surveys are traditional recreational bottomfishing areas, and it is highly likely that our results are influenced by past and present fishing activities. Since the majority of reef habitats in Puget Sound can be characterized as low-relief and low complexity in nature (Matthews 1990a), these habitats tend to be the easiest to fish on (i.e., result in less lost fishing tackle), possibly resulting in higher depletion rates than the more limited and difficult to fish high relief- high complexity habitats, and may account for the lower densities of rockfish and lingcod we observed in low complexity habitats. Studies comparing populations of rocky reef fishes within existing marine reserves traditional fishing areas are currently being conducted by the authors, and the results may provide greater insight regarding the effects of fishing on habitat use.

Summary

Despite problems of confusing terminology and a somewhat biased sampling protocol, our results suggest that macro- and micro-habitat features are important components influencing the distribution of copper and quillback rockfish in Puget Sound, and that these responses differ between the two species. Depth also appears to be an important factor controlling the distribution of quillback rockfish, although it remains unclear whether the preference of this species for deeper water is the result of competitive exclusion by copper rockfish, genetic adaptation, or some other factor. The importance of the macro- and micro-habitat features we examined was not as clear for lingcod and kelp greenling, which tended to be more mobile than the rockfishes, suggesting that our sampling protocol is not adequate for completely understanding habitat use by these species.

The patterns of habitat use exhibited by rockfish and, to a lesser extent, lingcod and kelp greenling, could have important ramifications in the design and placement of future marine reserves in Puget Sound. Specifically, if the goal of the reserve is to protect, preserve or rebuild populations of these species, the design should include the preferred macro- and micro-habitats of these species. Given the relatively small amount of rocky reef habitat in Puget Sound (Pacunski and Palsson 1998), capturing a diversity of preferred macro- and micro-habitats within a reef meso-habitat may be possible only through development of a linked system of smaller marine reserves.

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